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JAAiCEV/
1.174

41st AIAA Aerospace Sciences Meeting & Exhibit **(Statement A)**
(Reno, NV, 6-9 Jan 2003) **Deadline: 5 Jan 2003)**

Three-Dimensional Simulations of a Gas/Gas, Hydrogen/Oxygen Engine

6 January 03

Mark Archambault
Propulsion Directorate
Space and Missile Propulsion Division
Air Force Research Laboratory

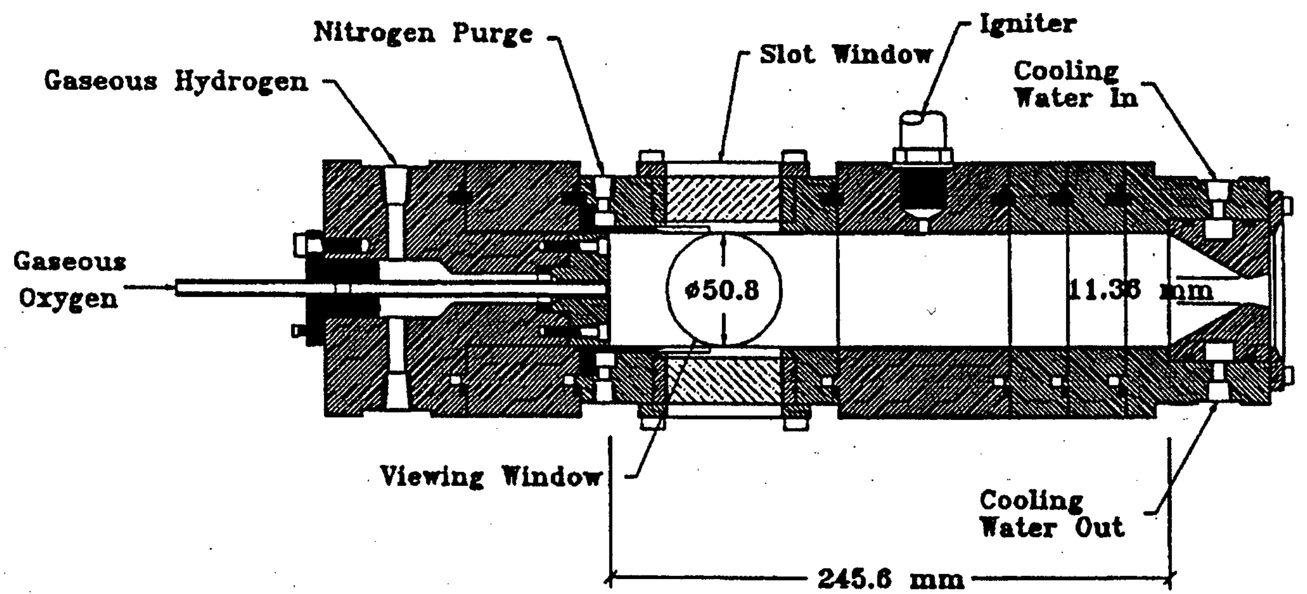
Oshin Peroomian
Metacomp Technologies, Inc.

Objective

- Develop design tools and methodologies for rocket injectors.
- Use experimental measurements to develop and anchor state-of-the-art flow codes.
- Determine level of fidelity required to reasonably reproduce the essential physical behavior of a coaxial gas/gas injector flow.

Previous Work

- Experiments — Penn State
  - OH-radical imaging
  - Velocity & species field measurements



from Foust, M.J., Deshpande, M., Pal, S., Ni, T., Merkel, C.L., & Santoro, R.J., "Experimental And Analytical Characterization of a Shear Coaxial Combusting GO_2/GH_2 Flowfield," AIAA 96-0646, AIAA 34th Aerospace Sciences Meeting & Exhibit, Reno, NV, Jan. 1996.

Previous Work

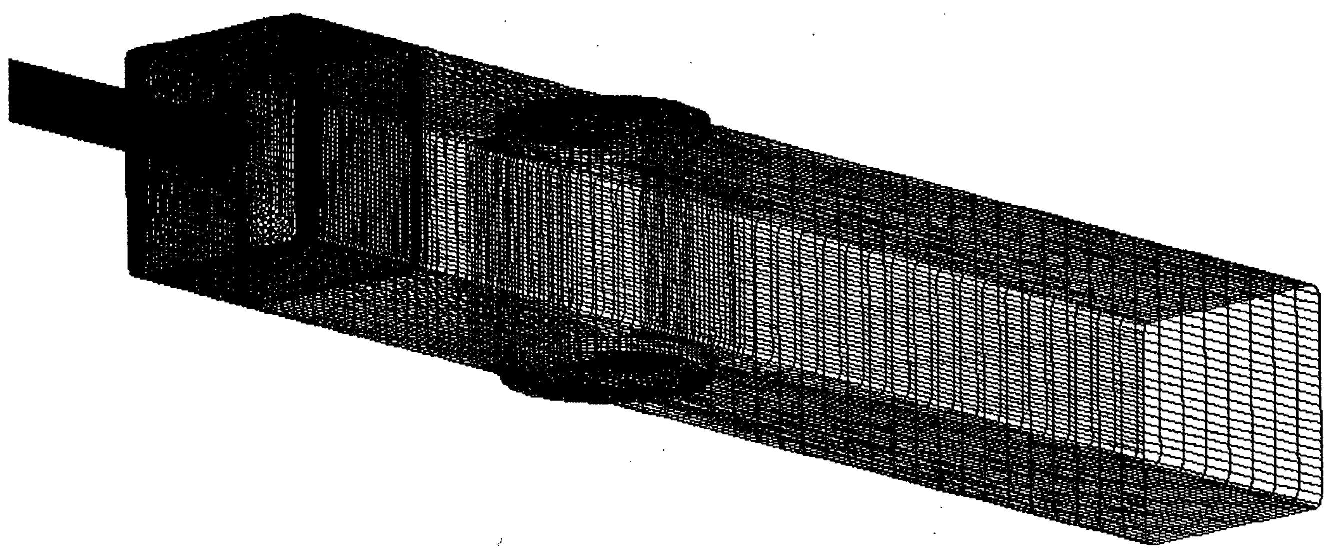
- Computational Modeling
  - DLR (AS3D)
    - 2nd-order explicit FV
  - MSFC (FDNS)
    - 3rd-order pressure-based predictor/multi-corrector
  - Penn State
    - 1st-order preconditioned, coupled, implicit, time-marching
  - AFRL
    - 2nd-order preconditioned, coupled, implicit, dual-time stepping. Steady and time-accurate.

Current AFRL Modeling Effort

- CFD++ from Metacomp Technologies
  - RANS, LES, hybrid RANS/LES
  - Compressible with high- and low-speed capability
  - Finite rate & equilibrium chemistry
  - 3D structured & unstructured grids
  - Explicit (RK) and Implicit schemes
  - Steady & Unsteady
  - Preconditioning
  - Parallel

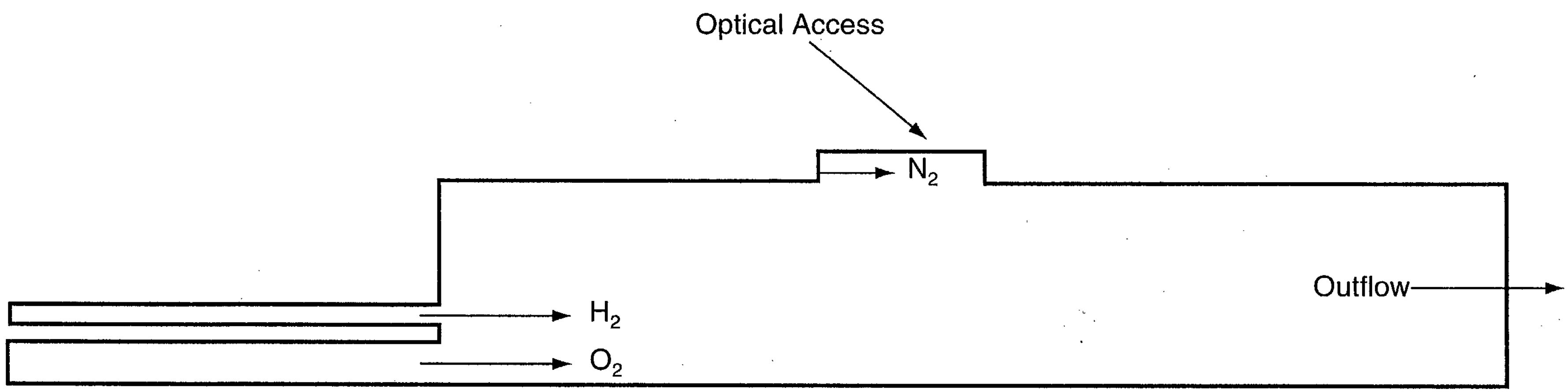
Current AFRL Modeling Effort

- Single-element, shear-coaxial, H_2/O_2 engine
- Refined grid resolution
- Steady & transient 3-D solutions
- Nitrogen curtain purge
- Prelude to multi-element analyses

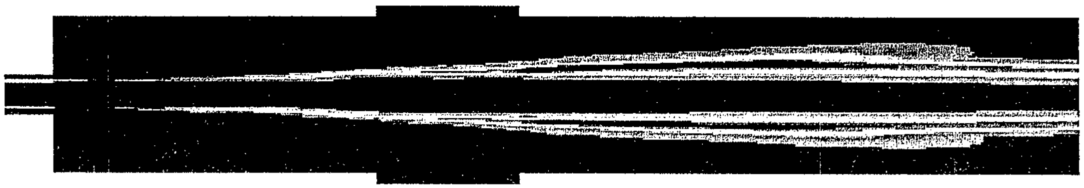


Current Computational Effort

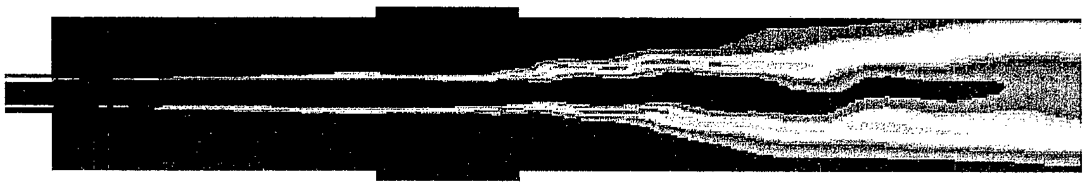
- Flow conditions
  - O_2 mass flow rate: 0.042 kg/s (0.1 lbm/s)
  - H_2 mass flow rate: 0.0103 kg/s (0.025 lbm/s)
  - N_2 mass flow rate: 0.01 kg/s (0.022 lbm/s)
  - Chamber pressure: 1.29 MPa
  - Inlet temperature: 297K
  - Laminar inlet flow, turbulence allowed to develop



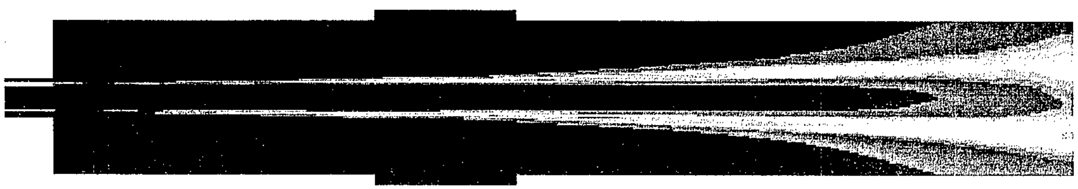
Current AFRL Modeling Effort



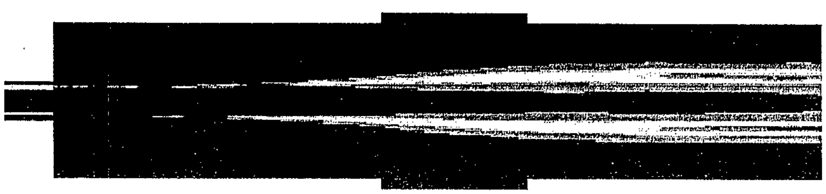
3-D Steady



3-D Instaneous

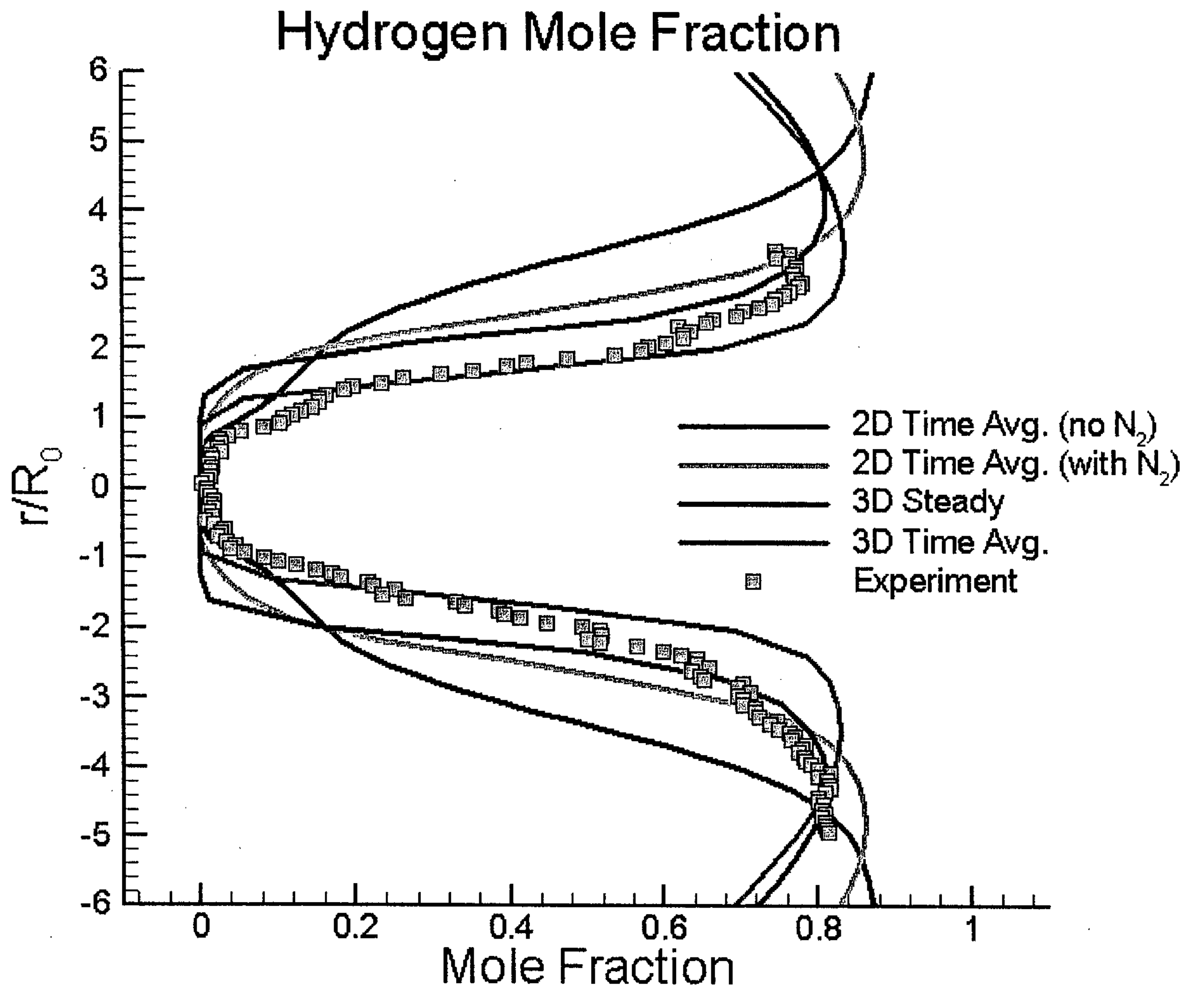


3-D Time-average



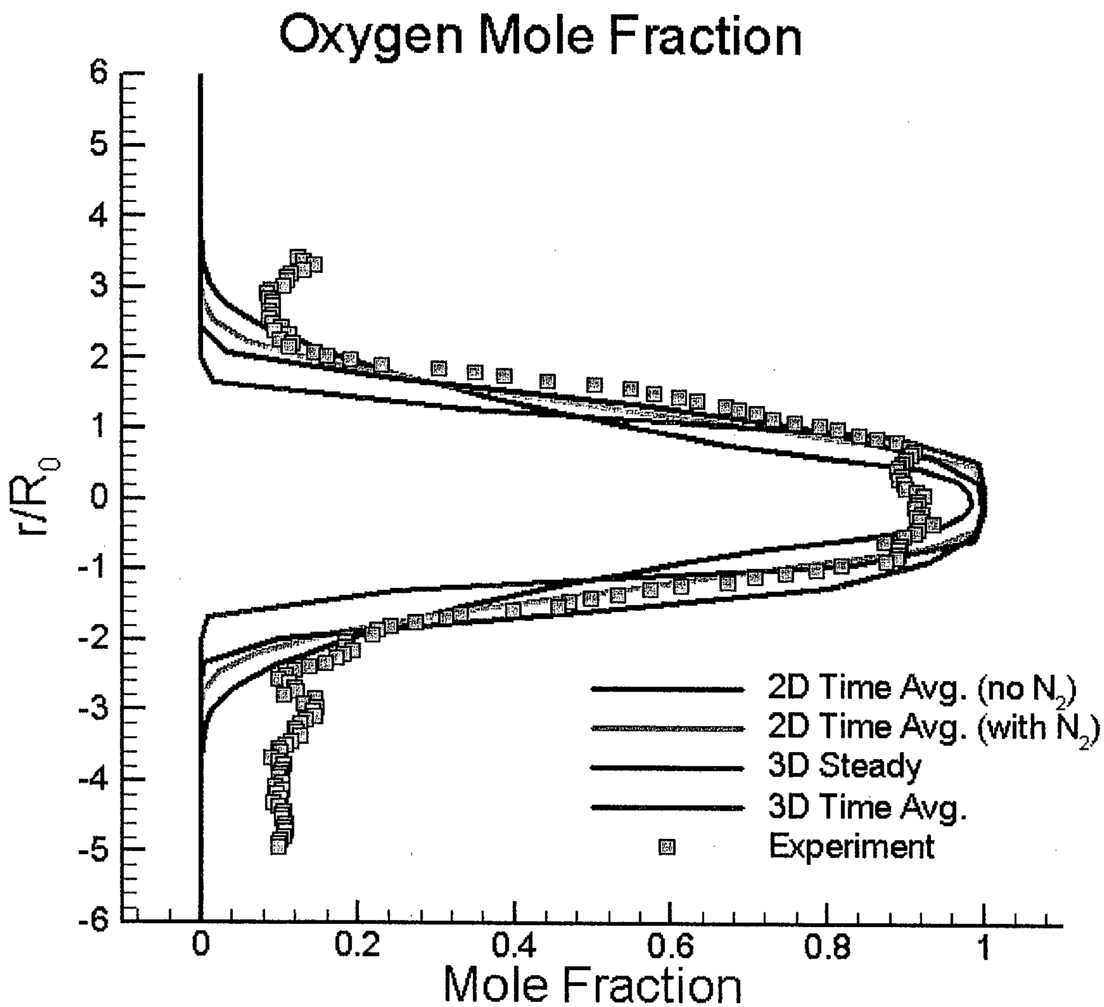
2-D Time-average

Current AFRL Modeling Effort



- Comparisons of level of modeling fidelity.
- 3D Time-avg. appears to provide best representation of data.
- No experimental uncertainties on data.

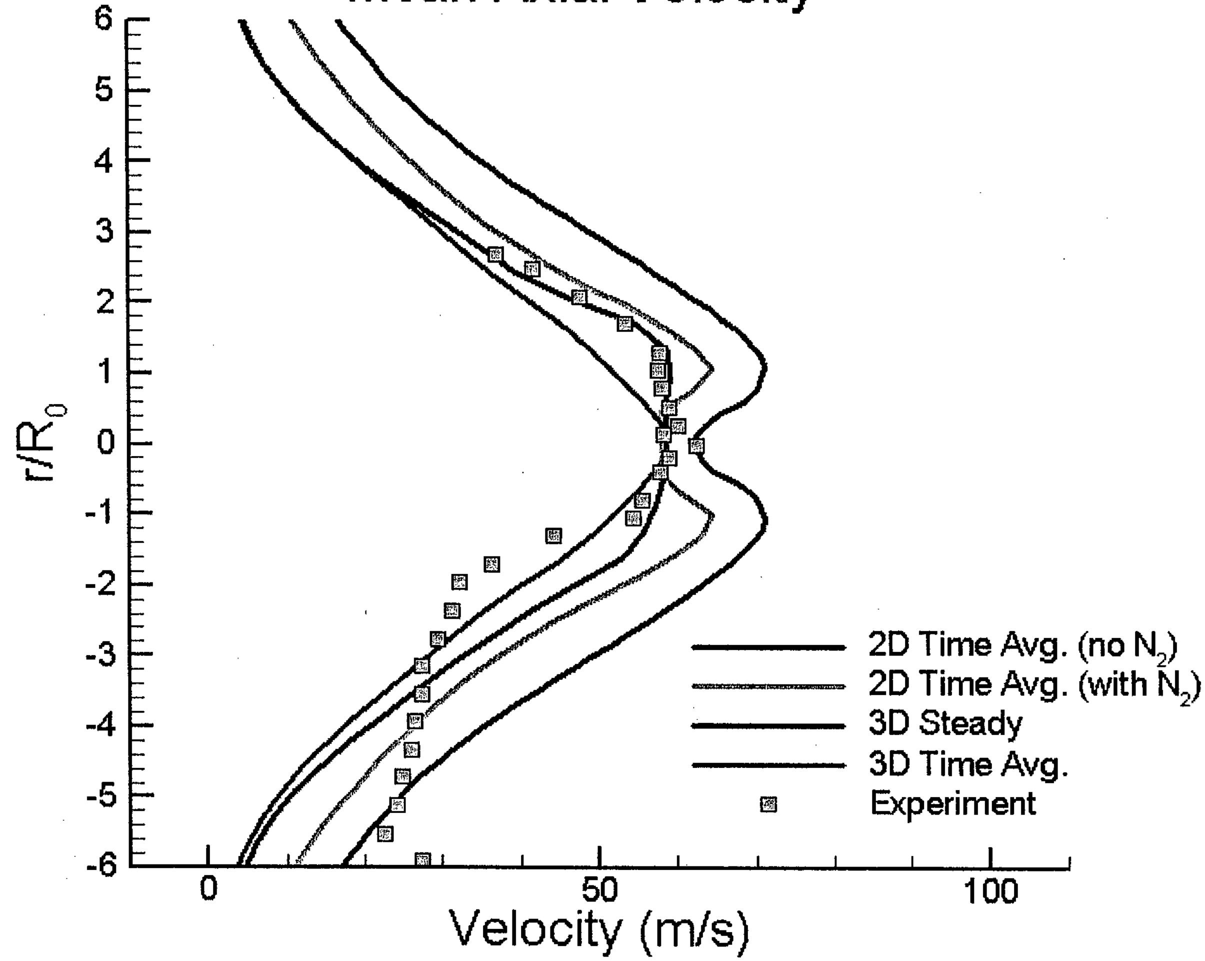
Current AFRL Modeling Effort



- Comparisons of level of modeling fidelity.
- Quantitatively similar profiles.
- 3D Time-avg. calculation deviates from data in outer part of shear layer possibly caused by flapping of actual flame.

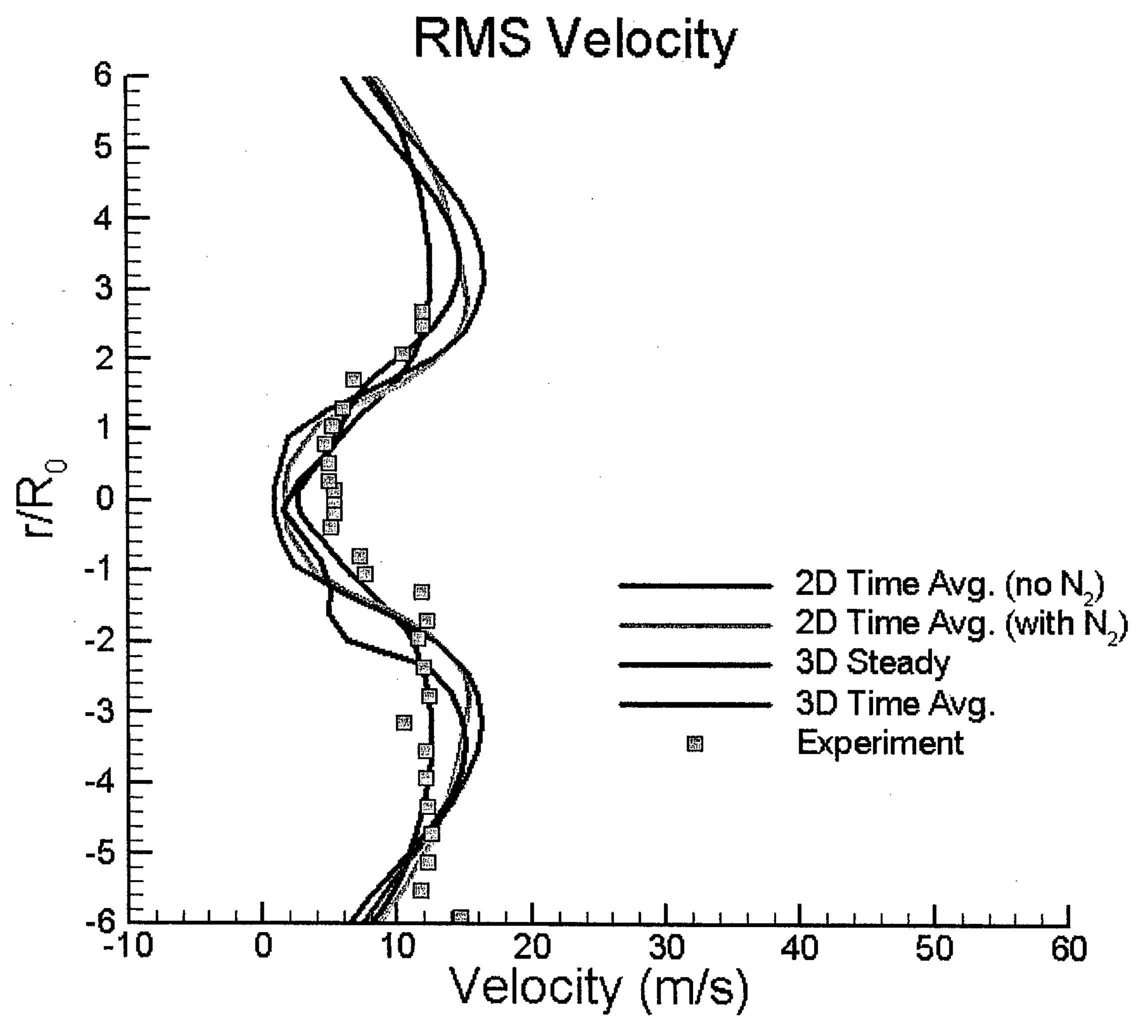
Current AFRL Modeling Effort

Mean Axial Velocity



- 3D results do not predict peaks in the velocity profile from the greater injection velocity of the hydrogen
- Differences are likely due to the three-dimensional chamber geometry.

Current AFRL Modeling Effort



- Calculations are quantitatively similar.
- Appears that RMS velocities are a strong function of turbulence model, but not very sensitive to the degree of fidelity.

Nitrogen Curtain Purge

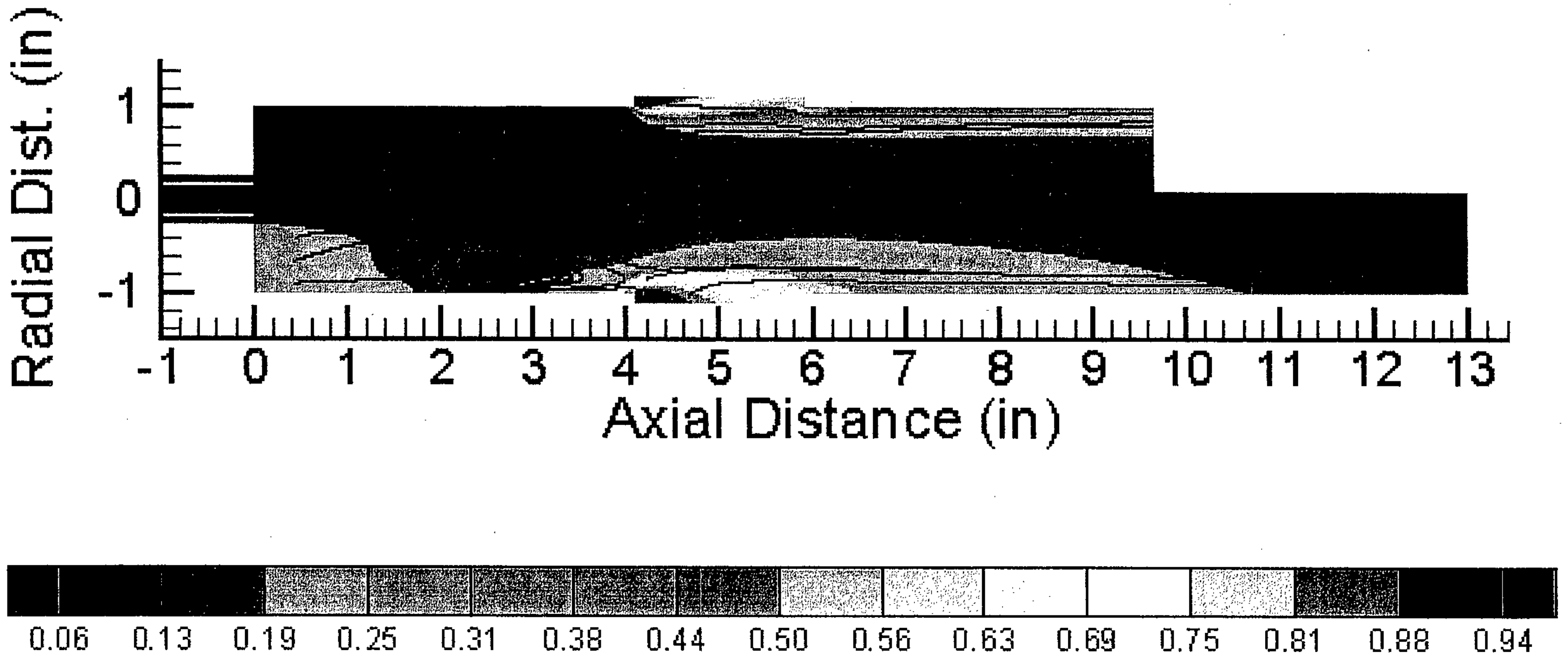
- Experimental feature used to cool optical access
  - Not likely to be in actual flight hardware

- Often neglected by modelers
  - Can result in deviation from experimental data in vicinity of wall

- In 2-D case, the windows are assumed to be axisymmetric. In 3-D case, the windows are located on top and bottom of chamber.

Nitrogen Curtain Purge

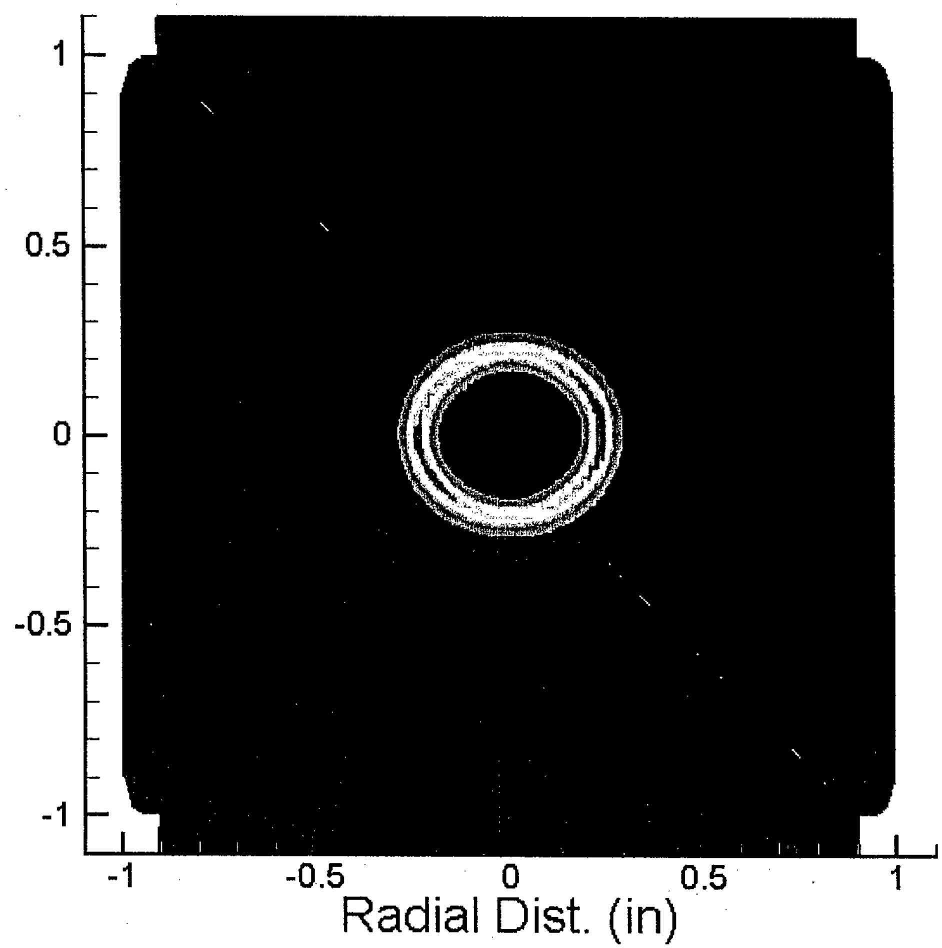
Contours of Nitrogen Concentration



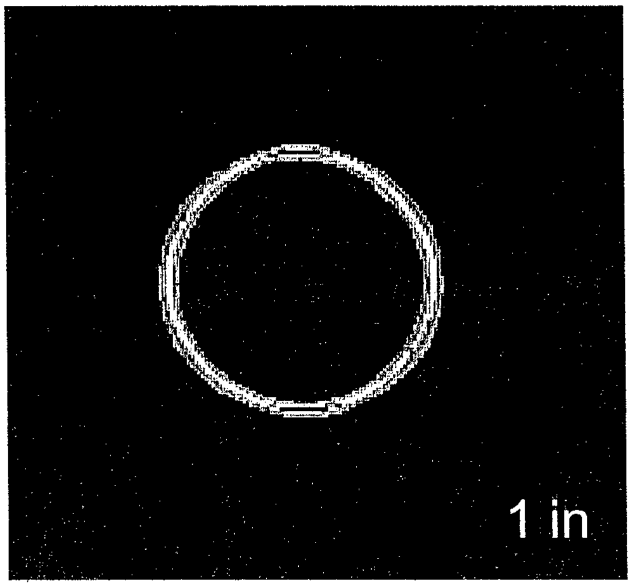
- 2-D (top half) compared with 3-D (bottom half).
- Slight shift forward of upstream recirculation zone in 3-D.
- Nitrogen being entrained upstream in 3-D case.

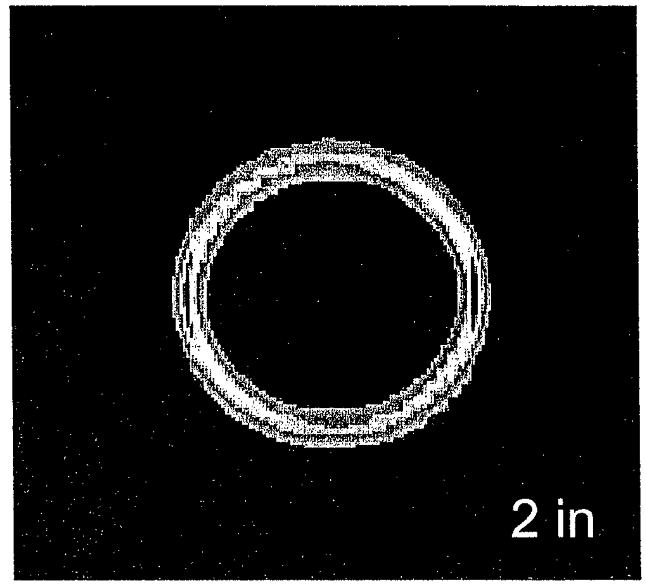
Current AFRL Modeling Effort

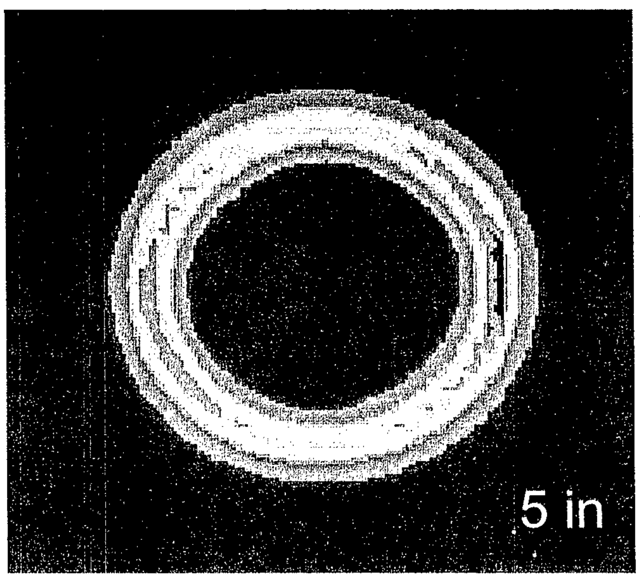
- No obvious three-dimensional patterns (such as helical structures) found.
- Slight variations in azimuthal direction can be attributed to the presence of the nitrogen purge.
- Suggests that planar or wedge symmetry could be used in future calculations.



Current AFRL Modeling Effort



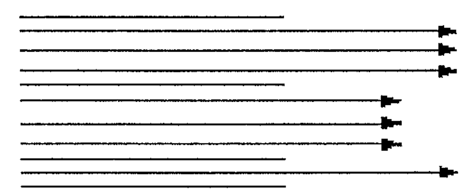




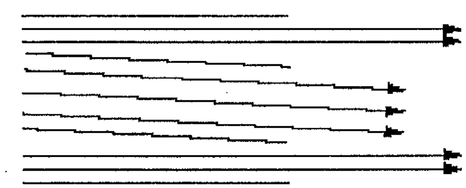
- Measurement indicates distance from injector.
- Streamtraces and contour plots do not indicate any temporal spatial changes in azimuthal direction.

Follow-On Plans

- Fully three-dimensional calculations
  - Oxygen Post Biasing
    - Off-axis parallel streams



    - Non-parallel streams



  - Multi-element injectors
  - Hydrocarbon
- Trend Analysis
  - Scalability

Summary and Conclusions

- Results indicate a marked difference between steady and time-accurate results. 3-D calculations seemed to predict the data as well as or better than 2-D calculations.
- A comparison between 2-D and 3-D models of the nitrogen purge showed differences that could be important when relying on CFD to design experiments.
- No evidence of 3-D patterns found in shear layer. Suggests that planar or wedge symmetry may be sufficient for future calculations.
- 3-D results are preliminary. Need to continue learning how to compute these types of flows to fully understand how to model this class of problems.